COMPUTER AIDED PROCESS PLANNING FOR DEEP DRAWN CYLINDRICAL COMPONENTS

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CERTIFICATE

This is to certify that the present work entitled "COMPUER AIDED PROCESS PLANNING FOR DEEP DRAWN CYLINDRICAL COMPONENTS" by Pritpal Singh Gambhir has been carried out under our supervision and has not been submitted elsewhere for the award of a degree.

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LIST OF SYMBOLS

D_b	Diameter of blank (mm)
D_c	Diameter of cup (mm)
D_d	Die throat diameter(mm)
D_i	Current cup diameter
D_p	Diameter of punch (mm)
DR	Draw Ratio (D_i / D_{i+1})
FTR	Flange Thickness Ratio (l / t)
H_c	Height of cup (mm)
BHF	Blank Holding Force (kgf)
PF	Punch Force(kgf)
PR	Percentage Reduction $100 (1- D_{i+1} / D_i)$
RR	Redrawing Ratio (D_i / D_{i+1})
TR	Thickness to Blank Diameter Ratio (t/D_b)
c	Die clearence (mm)
l	Width of the flange supported by a blank holder (mm)
$\bar{r}$	$= (r_0 + 2 r_{45} + r_{90} / 4)$ Normal Anisotropy
Δr	$= (r_0 - 2 r_{45} + r_{90} / 2)$ Planar Anisotropy
r_c	Cup Profile Radius (mm)
r_d	Die Profile Radius (mm)
r	Punch Profile radius (mm)
t	Sheet Thickness
σ_t	Tensile Strength (kgf/sq.mm)
σ_x	Modulus of strain hardening (kgf/sq.mm)
σ_y	Yield stress (kgf/sq.mm)

Nomenclature is shown in figure 1.1

ABSTRACT

In this thesis an attempt is made to develop heuristics for process planning of deep drawn components. These heuristics are extracted from general practice and experimental data. The developed system enables to get a feasible process plan for cylindrical shaped deep-drawn components. A computer program is developed in Pascal to calculate blank diameter for general shaped axisymmetric components with flange, cylindrical taper, flat ring and base elements. After input a graphical display of the component is provided. The program developed in Turbo-Prolog gives process plan for deep drawn cylindrical shape component. Given a geometrical shape and material of finished component, the program gives geometrical shapes, punch load and blank holding requirements at each stage. Logic is incorporated to work out annealing requirements based on strain hardening of the material. A set of guide lines are incorporated to minimize the number of [illegible] stages. After generating a process plan graphical display of different stages is provided.

CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

With the advent of automation in sheet metal industries and growing need for speed and accuracy, computers have become a necessary tool in the hands of engineers. Process planning is one such area which has attracted the attention of researchers, and it is a link between design and manufacturing activities.

Process planning procedure depends on the types of processes required to manufacture a component. Process planning of sheet forming operation requires complex geometrical manipulations combined with interrelated changes in material properties.

1.1 Introduction to Deep Drawing Process

Deep drawing is a process in which a blank or work-piece, usually controlled by a pressure plate, is forced into and/or through a die by means of a punch to form a hollow component where the thickness is substantially same as that of original material. Deep drawing is used to manufacture cans, air filters, cups, headlights and other similar components in automobile, aircraft, and other industries. Most of the deep drawn components are axisymmetric, even though rectangular and complex shapes are also formed by drawing.

Figure 1.1 shows different stages in deep drawing. The first stage is called cupping (Fig.1.1a). The other subsequent stages are called redrawing (Fig. 1.1b). Redrawing is carried out till the final cup is achieved. On the figure, various dimensions are indicated using symbols which are explained in nomenclature.

Figure 1.2 shows a sequential flow of metal in progressive stages of cupping. Consider the cupping stage A, after a small stroke of the metal volume element (2) of the blank is bent and wrapped around the punch nose. Simultaneously and subsequently the outer portions of the blank depicted by 3,4, and 5 move radially towards the center of blank, as shown in the cupping stage B and C.

Figure 1.3 (a) shows blank divided into the three zones X, Y, and Z. The outer annular zone X consists of material in contact with the die, the inner annular zone Y is initially not in contact with either the punch or the die and the circular zone Z is in contact with punch.

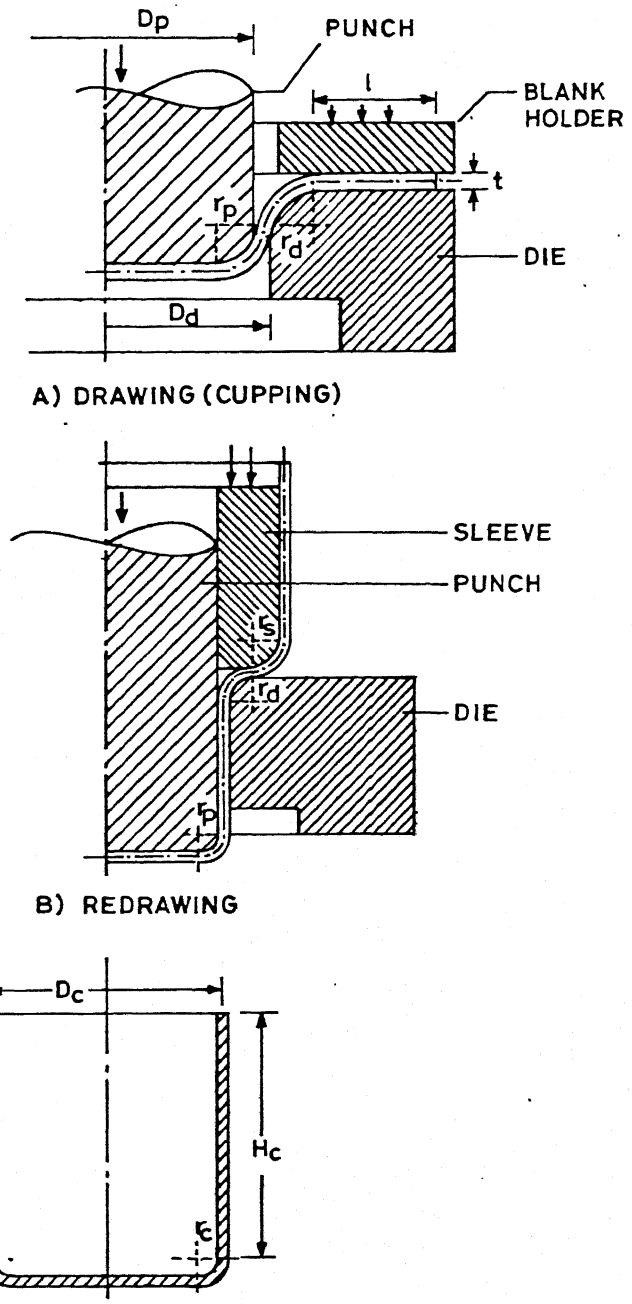
As the punch is moved downwards (Fig. 1.3 b), the following processes are observed during deep-drawing operation [1]:

1) Pure radial drawing between die and blank holder.

2) Bending, unbending and sliding over the die profile.

3) Stretching between die and punch.

4) Bending and sliding over the punch profile radius.



A) DRAWING (CUPPING)

B) REDRAWING

C) FINISHED CUP

FIG.1·1 VARIOUS STAGES IN DEEP-DRAWING.

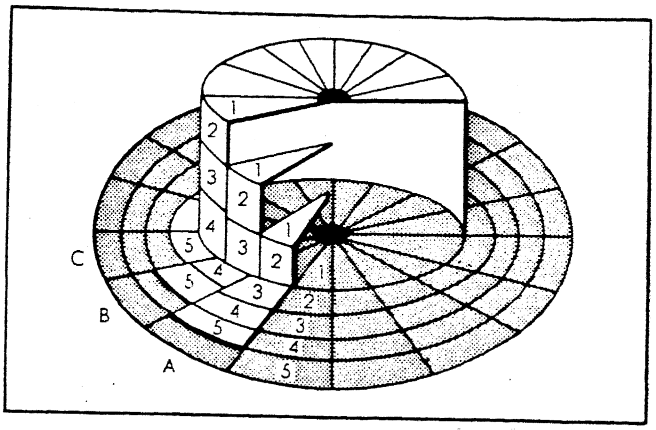


Fig. 1.2 : Sequential flow of metal shows progressive stages of cupping [12]

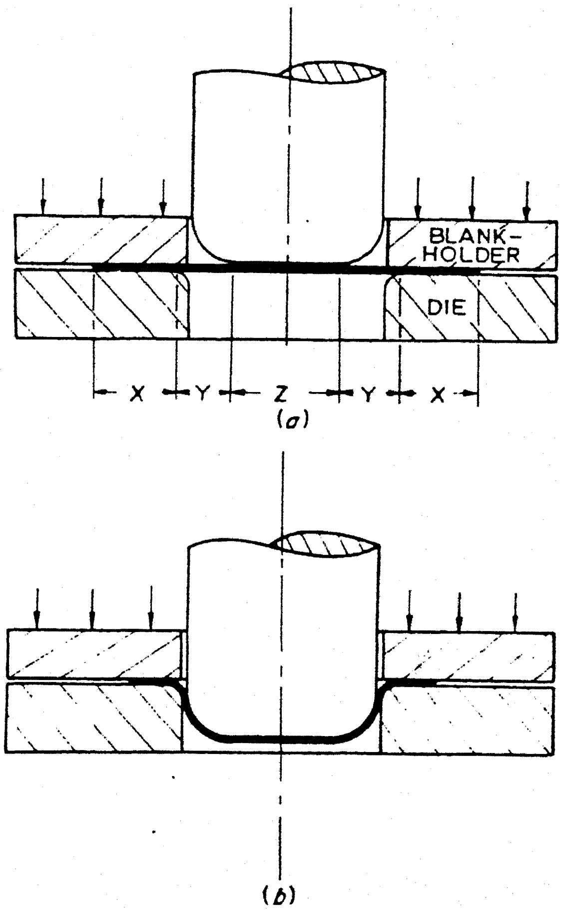


Fig. 1.3 : First stage drawing [1] .

5) Stretching and sliding over the punch head.

The first process thickens the material, whereas other processes thin it.

The plastic deformation in deep drawing depends upon the geometry of the component to be formed and material of the component. Due to large number of variables involved, process planning of deep drawing process requires expertise on the technical aspects and wide shop floor experience. The computer aided process planning (CAPP) requires a deep understanding of manufacturing technology, process planning methodologies, and data representation technique.

1.2 Literature Survey

Pioneering work in deep drawing was done by Chung and Swift [2] at the university of Sheffield in 1950. Chung and Swift used 4 in. diameter punch and varied blank diameter, punch profile, die radius, die angle, material, lubricant, blank holding force, and radial clearance and studied their effect on the punch force, thickness strain, and work done during the process. Eary [3] described details of experiments carried out to study effect of various parameters (geometrical and operational) on punch load.

Analytical treatment of deep drawing process has been done by many researchers. Johnson and Mellor [1]

analyzed deep drawing process based on Swift's work, as pure radial drawing using slab analysis and considering strain hardening. The thickness strain were calculated using Levy Mises flow rule. Fogg [4] developed a theory for redrawing of cylindrical cups through conical die without blank holder using the principle of minimum energy. Mellor and Sebaie [5] found two modes of instabilities in deep drawing. The first mode in cup wall occurs under plain strain tension. Second mode is in the flange under uniaxial tension. They also discussed the effect of strain hardening index (n) and normal anisotropy (r) on the limiting drawing ratio. Woo [6] predicted strains in the stretch forming region while drawing with a hemispherical punch. Avitzur [7] gave upper bound solution for deep drawing process.

Crane [8] described true stress-reduction relationship in uniaxial tension to find approximate stresses in the cup wall. Crane derived an equation to calculate maximum punch load using analogy of bursting thick pipe. Sachs [9] studied experimentally the process of drawing cylindrical cups, box shaped parts, redrawing operation and ironing of tubular parts.

Wilson [10] has given most of the data and guidelines of design practice in deep drawing. Lyman [11] has given detailed procedures for process planning used in deep drawing from practical point of view. Wick [12]

has described general principles used in deep drawing. Lange [13] has given a brief summary of analysis of deep drawing, considering radial drawing, bending and unbending at die radius, friction at die radius and flange. Jones [14] has reviewed industrial practice followed in die design and has given details of manufacturing sequence and tool arrangement for different shapes of deep drawn component.

Pitmann et. al.[15] have edited a compilation of papers on the finite element analysis of the drawing process. Some of the important contributions are due to Boynhm et. al., Tatenami et. al. and Nakamura et. al.. Boyahm et. al. have developed an axisymmetric finite element program using the rigid plastic approach for studying the deep-drawing process. Tatenami et. al. have considered deep-drawing process along with bending using an approach which is a combination of finite element method(FEM) and calculus of finite differences. Nakamura et. al. have proposed a numerical solution of deep drawing through tractrix die. Luo and Avitzur have suggested an upper bound approximation by deformation analysis.

Lee [16] has developed a computer software which is capable of predicting success or failure of formed sheet metal parts. Given geometrical shape of a component, the software predicts strains using FEM analysis. These strains are checked against forming

limits of the material obtained from shop floor.

James [17] developed a computer program, "Axiform" for the analysis of sheet metal parts. Predicted strains are compared with the forming limits. Press capacity and blank size are calculated for a given component. The program also predicts residual stress and spring back.

Duncan et. al. [18] presented a brief review of the methods of analysis for sheet metal forming process. They have also discussed their application as a basis for computer aids in design. Furthermore, they have suggested use of idealization of deformation process, materials, forming operations and shapes, which leads to approximate computer design aids for complex shapes. These design aids can be used effectively by experienced designers.

Eshel et. al. [19] developed a rule based system for automatic generation of deep drawing process outlines. A CAM representation of the required finished part is used as the input to the system which generates an output listing a set of highest priority process outlines. The finished part is represented as a concatenation of volumetric shape elements. It is a rule based system which includes a hierarchical structure of rules, generate & Test_and_rectify strategy, and automatic construction of inclusive test rule.

1.3 Computer Aided Process Planning Techniques

Process planning for machining operation consists of determining methods and sequence of machining a work piece to produce a finished component to design specifications [20]. In sheet metal forming process planning determines a detailed sequence of metal working operations to convert a blank or raw material to a required finished part [19].

In computer aided process planning (CAPP), computer is used to make certain decisions so as to improve consistency, accuracy and productivity. CAPP is broadly classified as 'Retrieval ' or 'Variant' and 'Generative' process planning.

Retrieval type CAPP systems use part classification and coding and group technology as a foundation. In this approach, parts produced in a plan are grouped into part families distinguished according to their manufacturing characteristics. For each part family, a standard process plan is established. This standard process plan is retrieved for new work parts which belong to that family. After few modifications,the retrieved process plan is used for new work part.

Generative process planning involves use of computers to create an individual process plan from scratch, automatically and without human assistance.

Generative process planning creates a process plan from facts (database) and rules (logic). Ideally, a true generative process planning system should be a turnkey system with all the logic contained in the software i.e. given all the attributes of a design component, the software should be able to give a feasible process plan for that component. Generative process planning can be accomplished by forward or backward planning. Forward planning starts with the raw material and proceeds towards a finished product, whereas the backward planning starts with a finished product and discovers the operation sequence by de-machining [20]. The main consideration in generative process planning is knowledge representation. The knowledge representation depends upon type of decision system used. The decision logic in the process planning can be represented by decision tree, decision table or by using a rule based system .

Decision tree is represented in 'if ; then' clauses. Although representing the decision tree is easy, expansion is difficult in case new decisions are to be incorporated.

Complex engineering data can be represented by decision tables. But implementation of decision tables needs a special data structure to be created in a base language or an outer language should be used to represent a decision table. But if an outer language is used, then interfacing capabilities with the base language are

essential.

Rule based systems are one of the most powerful technique to represent decision logic, normally associated with the human intelligence. The main components of the rule based system are facts, production rules and inference engine. Facts are represented by declarative knowledge like database. The system together with facts and rules is called a production system. Inference engine implements a control mechanism used to manipulate rules and facts.

1.4 Scope of the Present Work

In this thesis, an attempt is made to generate a process plan for deep-drawn components of cylindrical shape. Process planning is based on 'Generative' approach, with decision logic incorporated using rule based system. Forward planning is used because the shape at an intermediate stage is deterministic before hand and also the deformation process is strain-history dependent.

A program is developed using Turbo Pascal for calculating blank area for a generalized axisymmetric deep-drawn part. An other program using Turbo Prolog is developed to generate process plan for deep drawn cylindrical cups. Given a geometrical shape and material of finished component, program gives geometrical

shape at each stage, annealing requirements, tonnage required and blank holding requirements. The program also provides graphics display in order to compare relative shapes at each stage. The developed software is tested for thirteen different conditions of an illustrative component.

Chapter II deals with the background needed for process planning and formulating rules used for process planning. In chapter III details of a generalized system used to find blank diameter are described. Detailed process planning system is described in chapter IV and results are discussed in chapter V.

CHAPTER II

DEEP-DRAWING PROCESS

To carry out process planning activity, it is necessary to understand the deep-drawing operation in detail. Considerable efforts have been put into experimental investigations and analytical modeling by many researchers. However, exact behavior of the process variables such as friction and temperature variation is difficult to measure and formulate by modelling. In practice process planning of deep-drawing operations is carried out by applying empirical rules. In this chapter, deep drawing operation is discussed in detail, which forms the basis for the formulation of rules for the process planning system.

2.1 Stress conditions in deep drawing

Drawing load, applied at the cup bottom, is transmitted through cup wall to flange resulting in drawing of sheet. Figure 2.1 shows different elements at any instant of punch travel. Stress conditions of these elements are as follows:

(1) Element #1 in the cup bottom undergoes biaxial tensile stress along with sliding.

(2) Element #2 is subjected to bending over the punch profile at the start and sliding through out the process.

(3) Element #3 in the wall experiences stretching under

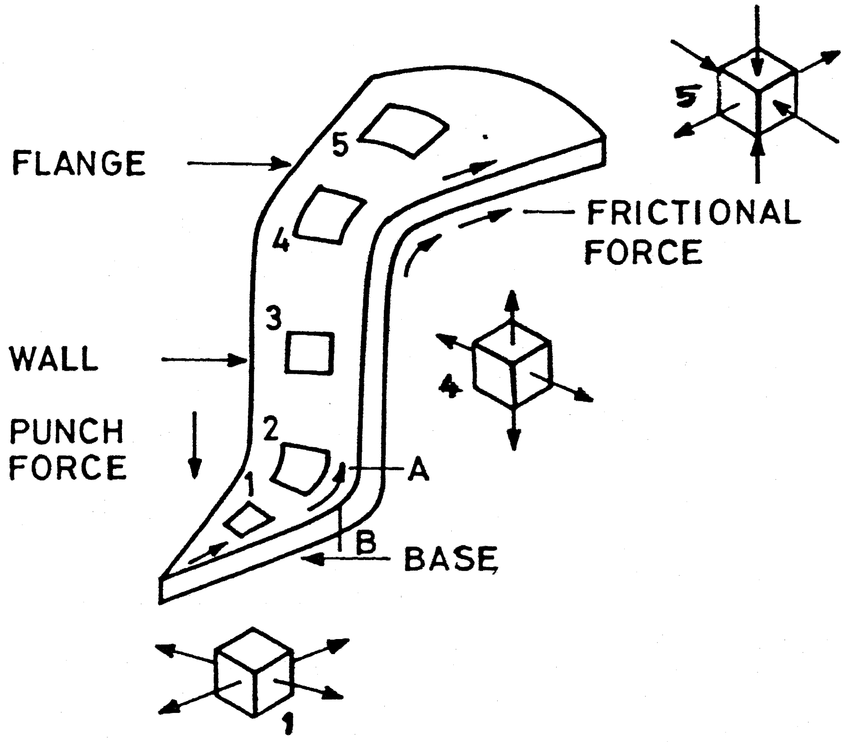


FIG. 2.1 VARIOUS STRESS ELEMENTS IN DEEP DRAWING.

the tensile load and displacement as drawing proceeds.

(4) Element #4 at the die profile radius undergoes bending over die profile and unbending under tension, along with frictional stresses as the element moves.

(5) Element #5 in the flange is subjected to radial tensile stresses, circumferential compressive stresses and normal and frictional stresses on the face. The elements in the flange take up position of element #4 and #3 as drawing proceeds, exhibiting non-steady nature of the deformation process.

The strains in the flange are compressive in the circumferential direction and tensile in the axial direction.

In redrawing, bending, unbending and sliding of previously formed corner at the punch profile radius is added to the drawing operation.

2.2 Process variables

The primary objective of deep-drawing is to deform a blank to form a cup without defects. Several defects such as (a) Fracture at the bottom, (b) Flange wrinkling, (c) Wall wrinkling, (d) Puckers, (e) Step-rings, (f) Orange peel, (g) Scratches, (h) Miss strike and (i) Burnishing may be observed in deep-drawing[3].

Tensile stresses greater than ultimate strength cause tearing of the cup at either A or B (Fig.2.1),

depending upon severity of thickness strain. Excessive compressive stresses in the flange may cause severe wrinkling.

The primary defects (a) to (d) are caused by tensile and compressive stresses and are avoided at the process planning stage by proper choice of process variables. The remaining secondary defects are eliminated by changing working conditions on the shop floor.

Percentage Reduction

The drawability of the sheet metal is expressed as percentage reduction(PR) from blank diameter to inside cup diameter.

$$PR = 100(1-D_b/D_p).$$

Limiting drawing ratio (LDR) is expressed as the ratio of maximum blank diameter to inside cup diameter. Thus,

$$LDR = D_b/D_p.$$

LDR is limited by maximum tensile load that can be transmitted by the sheet in the region of the cup wall or over the punch profile radius. LDR for a drawing stage depends upon tool geometry, t/D_b ratio, material properties, lubrication and to lesser extent on drawing speed.

As blank diameter is increased, keeping punch diameter constant, the maximum punch load increases [1]. Thickness strains at the punch profile radius and bottom

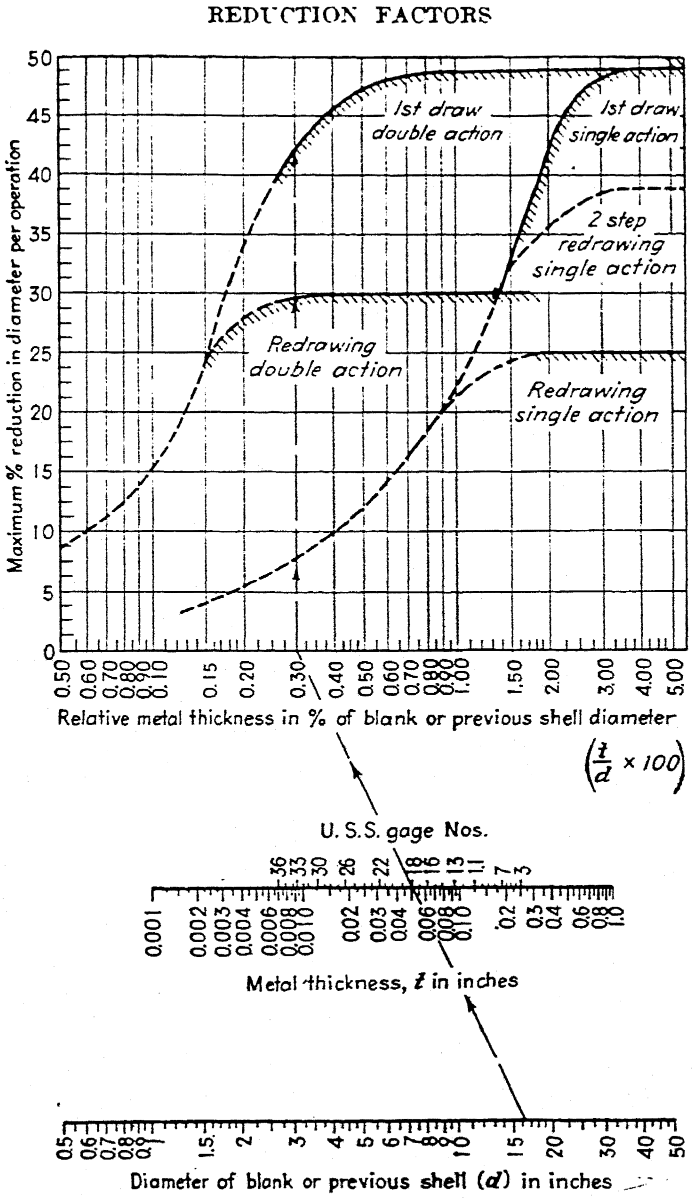


Fig. 2.2 : Tentative chart for determining maximum reduction (in diameter)[10]

of the cup (A and B Fig. 2.1) become severe with increase in LDR [1]. LDR increases as thickness to diameter ratio is increased. Figure 2.2 gives maximum possible reduction based on the thickness to diameter ratio, for drawing wrinkle-free cup without tearing at the bottom [10].

Punch Load

As drawing starts, punch load is required to overcome static friction and initial bending over the die, and punch profile radius. As drawing proceeds, punch force increases due to strain hardening attains a peak and gradually reduces with the reduction in width of flange (Fig. 2.3). The maximum punch load occurs at about one third of the stroke [3]. While drawing, maximum strain hardening takes place at the free end of cup. In redrawing, maximum load is attained at the end of ram stroke [21].

In order to select a press for particular drawing stage it is required to find maximum punch load. Analytical solutions to deep drawing process provide punch load equations which have to be integrated to find load during the travel of the punch. In practice, empirical relations are used to find maximum load required to accomplish drawing operation. Some of these relations are as listed below.

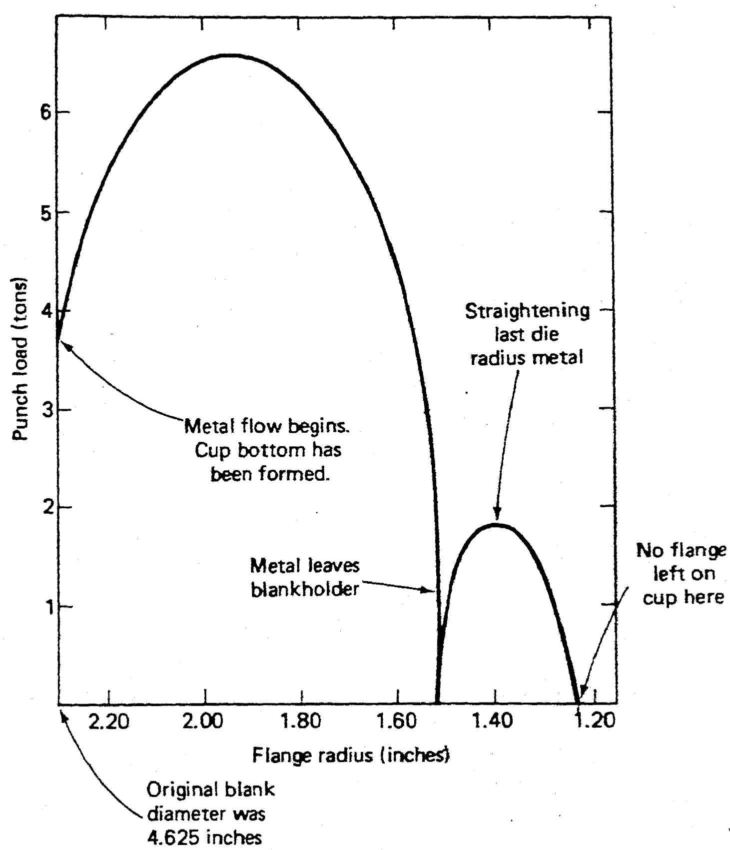


Fig. 2.3 : Force Analysis [3]

$$PF_{max} = \pi D_c \sigma_t t \left(\frac{D_i}{D_{i+1}} - K\right) \quad 0.6<K<0.7 \quad \text{----2.1 [10]}$$

$$PF_{max} = \pi D_c \sigma_t t \cdot 1.2 \quad \text{---2.2 [3]}$$

$$PF_{max} = \pi D_c \sigma_t t 2/\sqrt{3} \quad \text{---2.3 [7]}$$

The process variables which mainly affect percentage reduction and punch load are discussed in the following sections.

2.2.1 Punch profile radius

The more generous the punch profile radius, the more gradual is the rise of punch load and the longer the punch travel, but maximum punch load is almost unaffected [1].. The maximum punch load is not affected due to the fact that punch profile radius contributes to small initial bending force. IF $r_p > 10t$, then there are chances of puckering, and if $r_p < 2t$, it may cause tearing at the bottom region. If punch profile radius is kept between 4t to 10t then LDR does not change significantly [3]. For safer design the punch profile radius should be kept between 4t to 10t [10].

Punch profile radius for the first draw is taken as 10t and is reduced linearly for each successive redraw.

2.2.2 Die profile radius

Effect of die profile radius on the blank diameter is as shown in Fig. 2.4 . It is observed that the

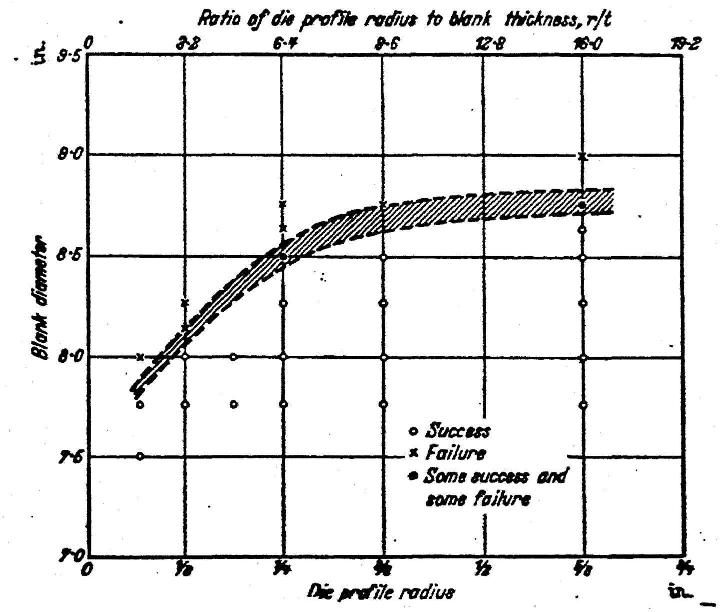


Fig. 2.4 : Effect of die profile on drawing capacity [2]

variation in the die profile radius up to 10t has significant effect on the LDR. Eary [3] showed that a sharp radius of 2t causes more heat to build up in the corner of the die material at die profile radius. Sharper the radius more difficult is the lubrication. Die radius below 10t increases bending and straightening forces resulting in reduced LDR. Increasing die radius above 10t does not improve LDR but increases tendency to wrinkle due to early release of blank from blank holder [1]. In practice die radius is kept between 4t to 10t.

2.2.3 Clearance between die and punch

Clearance between die and punch should be precisely governed. Larger clearance may cause either thickening in the top of the cup or puckering due to taper in the wall [1]. Inadequate clearance results in ironing in the top of the cup, increases punch load and danger of cracking at the bottom, and may cause welding between die and sheet[3]. If number of draws are more, mild ironing in cupping is permissible as it does not affect maximum punch load.

2.2.4 Blank holding pressure

The purpose of blank holder is to prevent wrinkling in the flange. If proper lubrication conditions are maintained, punch force is not significantly affected by blank holding force[3]. Two methods are used for blank holding, viz. clearance and pressure blank holding. In

clearance blank holding, a constant clearance or a taper is maintained between blank holder and die. Single acting die is used with clearance blank holder. Pressure blank holding provides a varying blank holding pressure and may need a double acting die.

Generally for thicker sheets (D_b/t < 25 to 40), the minimum blank holding force required is PF_{max} /3. Thinner sheets (D_b /t > 40) are especially sensitive to wrinkling because of low moment of inertia in buckling [13]. Thin sheets need greater blank holding force to prevent wrinkling [11].

Successful drawing without a blank holder depends upon ratio of supported length of blank (l) to thickness (t), amount of reduction, and t/D_b [11]. It is found that tendency to wrinkle is predominant in the cupping stage. In redrawing operation, blank holder is used to provide support to vertical walls.

2.2.5 Drawing speed

The maximum punch force and LDR are almost independent of the drawing speed [3]. But speed (strain rate) affects efficiency of lubrication and yield stress of material [1]. Generally high speed drawing is suitable where surface finish is not important.

Practical limitation on drawing speed is set by fatigue of press and speed of the feeding

mechanism. Drawing speed is generally adjusted on the shop floor to suit particular requirements.

2.2.6 Friction

Friction conditions between blank-blank holder, blank-punch, and blank-die, have marked effect on LDR. It is observed that no lubrication between punch and blank and good lubrication between blank and die give best possible conditions. If punch is kept rough then neck shifts from B to A (Fig. 2.1) [22]. Generally this variable is controlled by the foreman or die setter [3]. Maximum punch force reduces with effective lubrication.

2.2.7 Material properties

LDR ratio strongly depends upon normal anisotropy (r-value). With increase in r-value, flow stress in the flange is lowered and flow stress in biaxial tension in the cup bottom is increased, resulting in improved LDR.

Ears are formed if planar anisotropy (ΔR) is greater than zero. Smaller planar anisotropy is preferred for deep drawing of cylindrical cups. A material having low yield stress causes more thickness strains at the bottom [1]. Strain hardening coefficient n has little effect on LDR [5].

2.3 Redrawing

Redrawing facilitates the production of deeper and narrower cups. If the first drawing operation cannot produce a cup which is deep, (because of limited drawing at cupping stage), redrawing has to be employed. If the first redraw still can not produce the final cup, a second redraw is employed, and so on. Redrawing is accomplished using either direct or indirect method.

CHAPTER III

BLANK SIZE DETERMINATION

In this chapter an approach for the determination of blank size for axisymmetric deep drawn components is presented. Accurate determination of blank size is the first typical step towards process planning in order to reduce scrap. Use of larger blank diameter, unnecessarily increases the drawing ratio and likelihood of failure.

It is assumed that the thickness of sheet remains constant during drawing and circular blank shape is used for axisymmetric component.

3.1 Methods for determining blank size

Various methods have been used to determine the size of blank for drawn shells. These methods are based on:

1) Mathematical formulae.

2) The use of graphical layouts.

3) Combination of graphical layout and mathematical formulae.

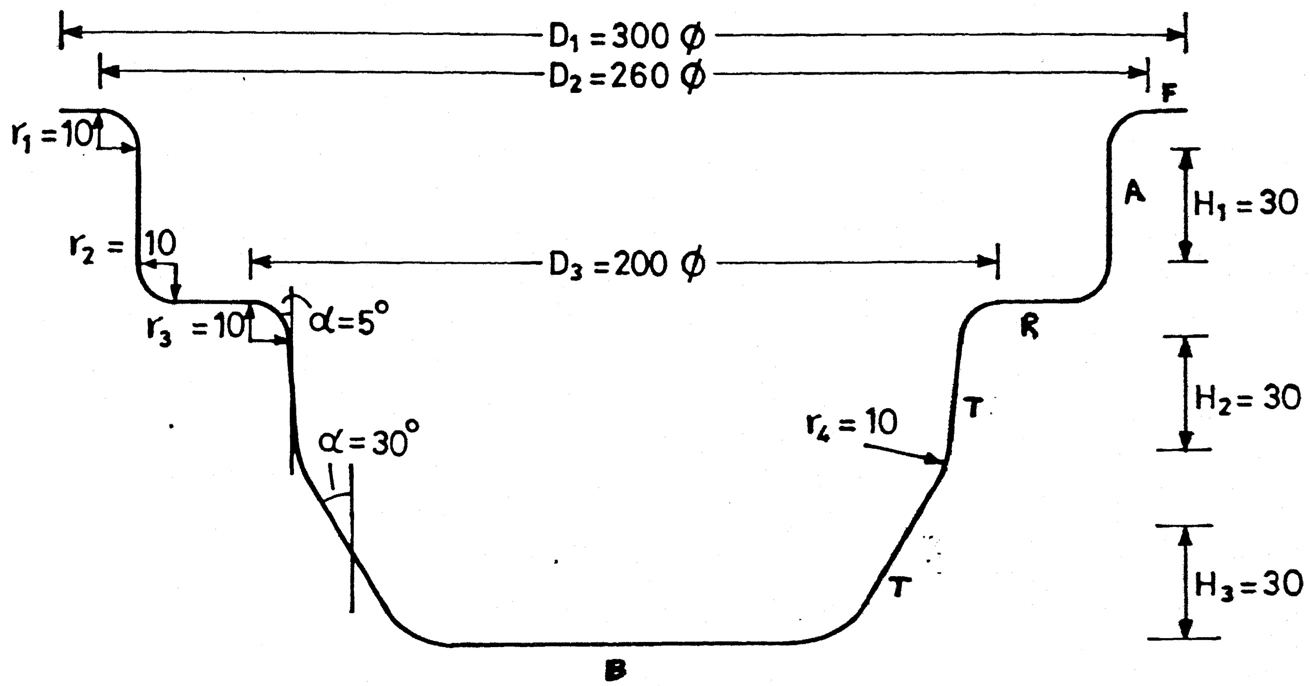
In the analytical method, the surface area of the component to be drawn is calculated using formulae and equated to surface area of blank, thus determining blank size. In graphical method surface area of the component is determined by the rule of Guldinus,[10] which states that the area is equal to length of the profile times the length of

the path of its center of gravity. With the area of component known, the blank diameter is calculated. The third method, as name suggests, uses combination of graphical and mathematical formulae in order to find out the blank diameter.

3.2 Computerized determination of blank size

A computerized methodology has been developed to determine blank size of deep drawn components having uniform thickness using following approach. The component is divided into primitive elements such as flange, annular, ring, taper, and base element(Fig. 3.1). At the end of each element, a corner radius element is specified. The program is designed in such a way that after selecting an element, only next feasible elements which can build component are prompted for next input. Input to the program for the component is given by starting from top and proceeding towards bottom. The general format for deciding about the next possible element is given in Fig. 3.2. Figure 3.1 shows a hypothetical component whose specifications are listed in Table 3.1. The user provides the input in an interactive fashion starting with the first element. The thick lines shown in figure 3.2 indicate the path selected for input of information for the component in Fig. 3.1.

As pointed out earlier adjoining elements are connected by an arc whose radius is specified. The program calculates the angle of the arc segment connecting the adjoining elements. For each element, the area is calculated



ALL DIMENSIONS IN MM

FIG. 3.1 HYPOTHETICAL COMPONENT

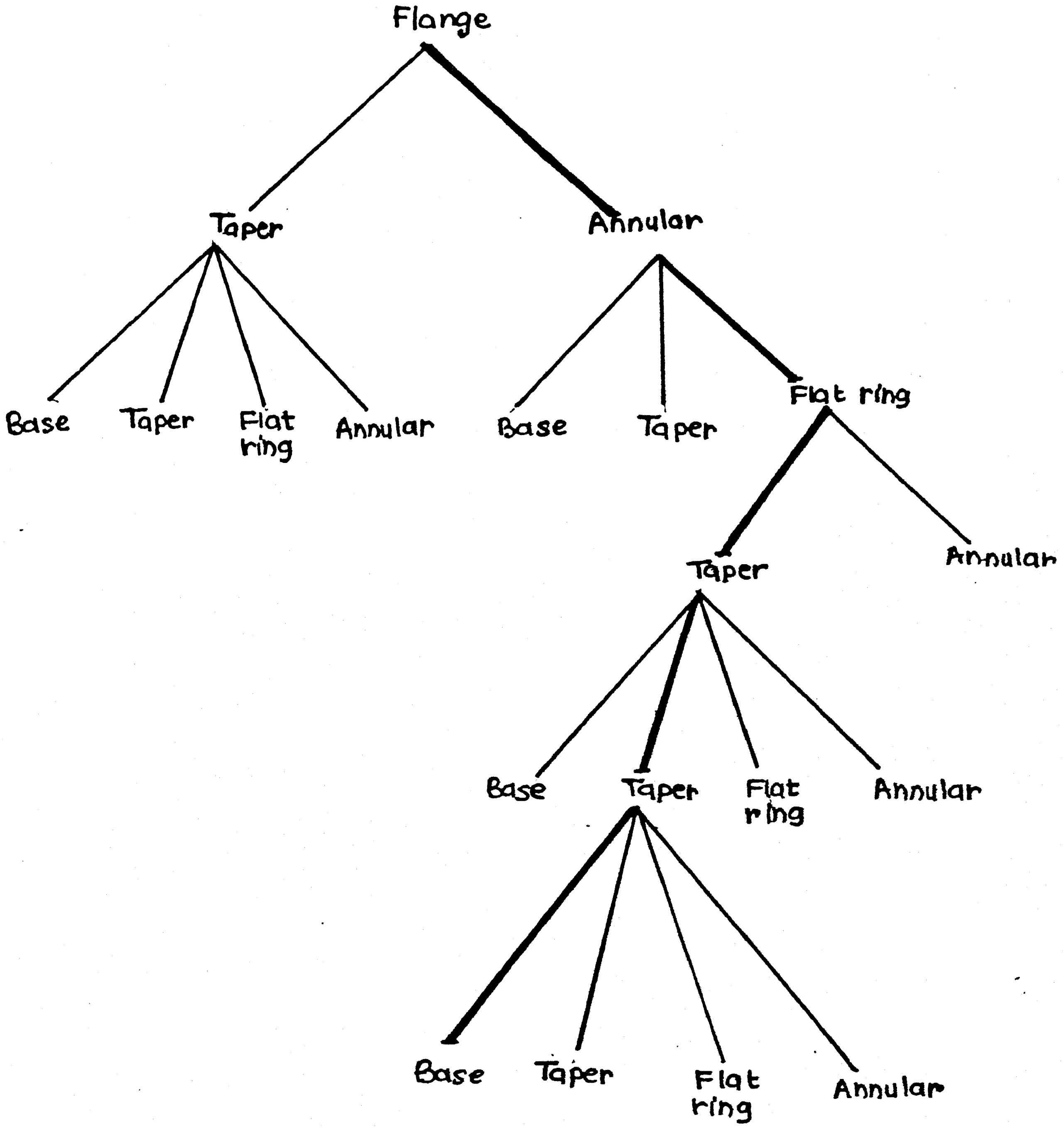


Fig. 3·2 Tree For Deciding next element.

Table 3.1 Input for the component shown in Fig 3.1.

S.No.	Element	Code	Attributes	Input Values of attributes
1	Flange	F	D1,D2,r1	300,260,10
2	Annular	A	H1,r2	30,10
3	Flat ring	R	D3,r3	200,10
4	Taper	T	H2,α1,r4	30,5,10
5	Taper	T	H3,α2,r5	30,30,10
6	Base	B	-	-

using the formulae given in Table 3.1. Total surface area of elements of the drawn component is equated to surface area of the blank. The blank diameter is obtained from the equation:

$$D_b = \sqrt{4 / \pi \sum_{i}^{n} A_i} \qquad \ldots\ldots 3.1$$

where

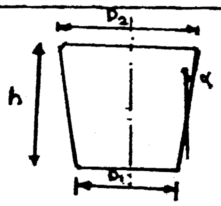
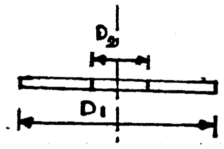
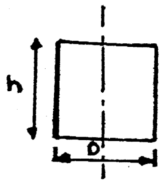
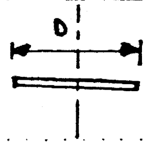
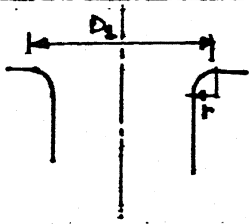
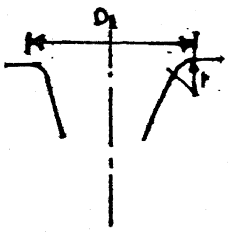
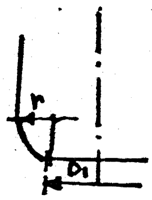
A_i is surface area of i^{th} element.

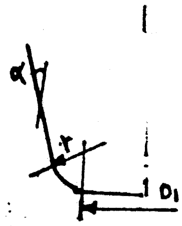
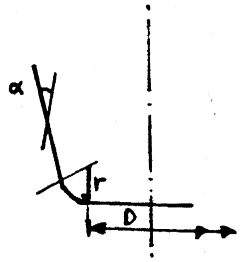
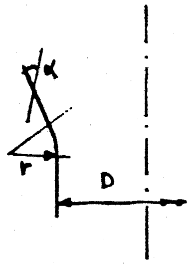
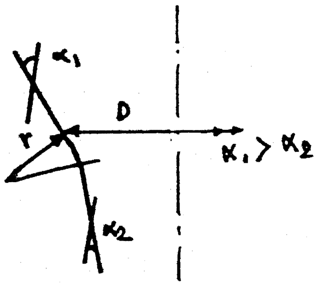
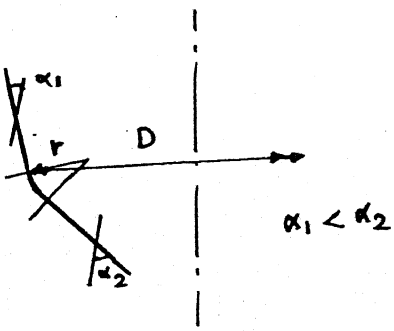
n is number of elements specified.

For the hypothetical component the required blank diameter is 439.50 mm.

The computer program is written in Turbo Pascal in order to facilitate graphical display of the component based on the input dimensions of the various elements. The blank diameter, and the attribute data of the various elements is stored in a file which may be used as basic input to the process planning phase.

Table 3.2 Equations for areas of axisymmetric deep drawable part

Element Number	Element Type	Drawing	Formulae For surface area
1	Taper		$\pi h(D_2+h)/\cos\alpha$
2	Ring or Flange		$\pi/4\ (D_1^2 - D_2^2)$
3	Annular		πDh
4	Base		$\pi/4\ (D^2)$
5	Flange +Radius +Annular		$(\pi^2 rD_1/2 - 2r^2\pi)$
6	Radius +Taper		$\frac{\pi^2 D_1 r(90-\alpha)}{180} + 2\pi r^2(\cos(\frac{(90-\alpha)\pi}{180})-1)$
7	Annular +Radius +Base		$\frac{\pi^2 r D_1}{2} + 2r^2\pi$

Element Number	Element Type	Drawing	Formulae For surface area
8	Annular +Radius +Base		$\frac{\pi^2 D\alpha}{180}$ $-2\pi r^2\left(\frac{\alpha\pi}{180} - \sin\left(\frac{\alpha\pi}{180}\right)\right)$
9	Taper +Radius +Base		$\frac{\pi^2 Dr\,(90-\alpha)}{180}$ $-2\pi r^2\left(\cos\left((90-\alpha)\frac{\pi}{180}\right)-1\right)$
10	Taper +Radius +Annular		$\frac{\pi^2 Dr\,\alpha}{180}$ + $2\pi r^2\left(\frac{\alpha\pi}{180} - \sin\frac{\alpha\pi}{180}\right)$
11	Taper +Radius +Taper		$\frac{\pi^2 Dr(\alpha_1-\alpha_2)}{180}$ $-2\pi r^2\left(\sin\alpha_2\frac{\pi}{180} - \sin\alpha_1\frac{\pi}{180}\right.$ $\left.+\cos\alpha_1\frac{\pi}{180}\times\frac{(\alpha_1-\alpha_2)\pi}{180}\right)$
12	Taper +Radius +Taper		$\frac{\pi^2 Dr\,(\alpha_2-\alpha_1)}{180}$ $+2\pi r^2\left(\frac{(\alpha_2-\alpha_1)\pi}{180}\cos\alpha_1\frac{\pi}{180}\right.$ $\left.-\sin\frac{\alpha_2\pi}{180} + \sin\frac{\alpha_1\pi}{180}\right)$

CHAPTER IV

PROCESS PLANNING OF CYLINDRICAL SHAPED CUPS

In this chapter an approach for process planning of cylindrical shaped components is presented. As pointed out earlier, the process planning activity in deep drawing heavily relies on practical experience and experimental data. After process planning finer adjustments in tooling are done at the shop floor. In the following sections the process planning system, its design and implementation are discussed.

4.1 System Description

For the development of the process planning system following assumptions are made.

1) Material used is in as received condition.

2) Input to the system is a deep drawable cylindrical shaped component.

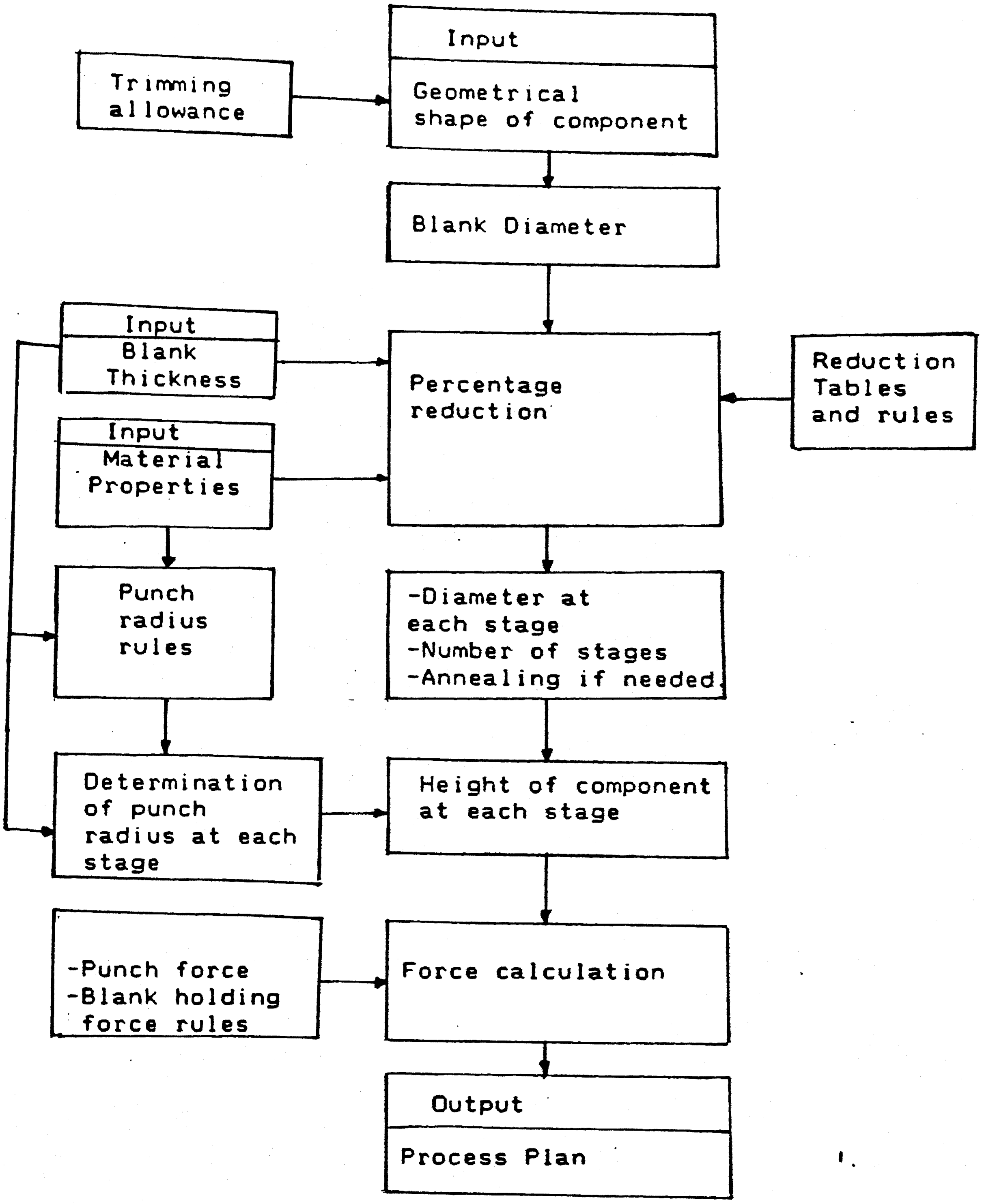
3) The end properties are not taken into account.

4) Direct redrawing method is used for redrawing.

5) No ironing takes place during the process.

4.2 System analysis and design

Figure 4.1 illustrates the general logic diagram for process planning of cylindrical shaped cups. The process planning system developed is divided into the following three modules:



4.1 General logic diagram for process planning of cylindrical shaped cups.

1) Input module.

2) Process plan generation module.

3) Output module.

The inputs to the first module are height, diameter, component profile radius, thickness and material properties.

The second module generates feasible geometric shapes and calculates punch force and blank holding force required at each stage. The various process planning steps carried out in this module are described below.

4.2.1 Design steps in process planing

1) Add trimming allowance to height of cup.

2) Determine blank diameter.

3) Select percentage reduction for drawing and redrawing.

4) Determine number of stages, diameter at each stage and stage at which heat treatment is required, if necessary.

5) Select optimal punch and die profile radius.

6) Determine height of cup at each stage.

7) Determine punch force.

8) Determine blank holding force, if needed.

These steps are explained in detail as follows:

1) Trimming allowance

Ears are formed at the cup edge or in the flange during the process of drawing, which results in a wavy or non uniform cup height. The ears are also formed due to uneven friction conditions, planar anisotropy, unequal blank holding pressure and off-center placing of blank. The uneven edges

Table 4.1 Trimming allowance based upon cup diameter [3].

Cup diameter mm.	Trimming allowance mm.
$25 > D_c$	1.5
$25 \leqslant D_c < 50$	3.0
$50 \leqslant D_c < 100$	6.0
$100 \leqslant D_c < 150$	12.0
$150 \leqslant D_c$	20.0

Table 4.2 Percentage reduction factors for drawing cylindrical shells without flange for mild steel and brass [11 ,13]

	Cupping	Redrawing			
t/D_b %	Draw	1St.	2nd.	3rd.	4th.
$2.0 < t/D_b$	0.52	0.27	0.24	0.22	0.20
$1.5 < t/D_b < 2.0$	0.50	0.25	0.22	0.20	0.18
$1.0 < t/D_b < 1.5$	0.47	0.24	0.21	0.19	0.16
$0.6 < t/D_b < 1.0$	0.45	0.22	0.20	0.18	0.15
$0.3 < t/D_b < 0.6$	0.42	0.21	0.19	0.17	0.14
$0.15 < t/D_b < 0.3$	0.40	0.20	0.18	0.15	0.13
$0.08 < t/D_b < 0.15$	0.37	0.18	0.16	0.14	0.12

Table 4.3 Percentage reduction factors for drawing cylindrical shells without flange for aluminum [3]

t/D_b %	Cupping	Redrawing		
	Draw	1st.	2nd.	3rd.
$t/D_b > 0.4$	0.48	0.30	0.24	0.19
$0.4 > t/D_b > 0.3$	0.45	0.28	0.22	0.17
$0.3 \geq t/D_b > 0.25$	0.40	0.24	0.19	0.14
$0.25 > t/D_b > 0.15$	0.35	0.20	0.06	-

Table 4.4 Blank holding force as a percentage of punch force [11]

t mm.	BHF	t mm.	BHF
0.127	85 PF	0.762	39 PF
0.25	67 PF	1.270	23 PF
0.381	57 PF	1.800	14 PF
0.5	50 PF	2.540	09 PF
0.635	44 PF	3.175	8.5 PF

are trimmed after drawing. To compensate for this, trimming allowance is added to blank diameter or height of cup. The trimming allowance depends on the cup diameter. Table 4.1 lists the trimming allowance needed for various cup heights.

2) Blank diameter

Blank diameter is calculated by equating surface area of the cup to surface area of the blank. In deep drawn components thickness does not remain constant, but it is assumed that thinning at the bottom and thickening at the top of the cup compensate each other. Diameter of the blank is determined using the blank diameter determination procedure outlined in chapter 3.

3) Percentage reduction

The maximum possible reduction at each stage is used. These percentage reductions are chosen on the basis of blank material and t / D_b ratio. Percentage reductions used in current implementation are taken from various sources [3,11,13]. Tables 4.2 and 4.3 give the percentage reductions admissible for mild steel, brass, and aluminium.

4) Number of stages and heat treatment requirement

The number of stages necessary to obtain finished cup depend on the total reduction required. The flow stress in cup wall increases after each reduction due to strain hardening. If the flow stress exceeds the maximum limit, then

local necking takes place at weak points. The increase in the flow stress is given by the true stress-area reduction diagram in uniaxial tension.

The true stress-area reduction curve as shown in the Fig. 4.2 is approximated to a linear curve [8]. It is shown ~~assumed~~ that reduction in drawing corresponds to the area reduction in uniaxial tension. The maximum flow stress in cup wall at the n^{th} stage is given by following expression :

$$\sigma_N = \sigma_y + R_n (\sigma_x - \sigma_y) \qquad \text{----------- } 4.1$$

where

R_n Total reduction upto n^{th} stage.

σ_N Flow stress at the n^{th} stage.

σ_y Initial flow stress.

σ_x Modulus of strain hardening [8].

R_n is calculated by following expression :

$$R_n = 1 - ((1 - R_1) (1 - R_2) \ . \ . \ .) \qquad \text{---------- } 4.2$$

If flow stress induced in cup is greater than the maximum permissible flow stress, annealing is required before further deformation is carried out. It is assumed that, after annealing, original properties are restored. In some cases it is observed that if annealing is done at an early stage, it is possible to reduce total number of stages. To reduce total number of stages, possibility of annealing at a previous stage is investigated. The output consists of the minimum number of drawing stages along with the minimum annealing

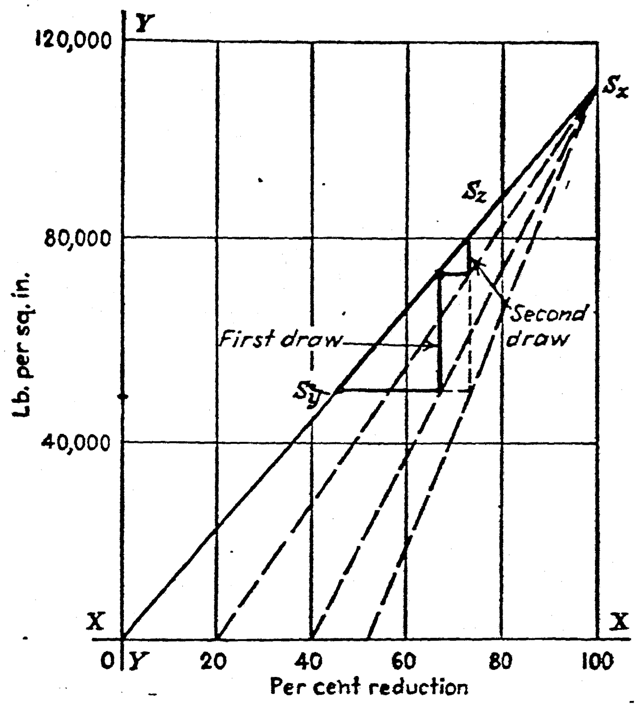


Fig. 4.2 : Change in strain-hardened condition [10].

stages required to obtain finished the cup.

5) Punch profile radius

The punch profile radius is kept between 4t to 10t. Maximum punch profile radius is used for cupping and it is reduced linearly for the subsequent redraws upto minimum punch profile radius. If the punch profile radius r_p is greater than 0.3 times the current cup diameter D_i then r_p is taken as 0.3 D_i [9]. If the punch profile radius of the final cup is less than minimum punch profile radius, then cracking may occur at the bottom. In order to avoid cracking at the bottom, sizing stage is introduced with minimum punch profile radius.

6) Height of cup

Once the diameter of punch profile radius at each stage is known, the height of cup is determined by assuming that the cup surface area remains constant. The height of cup at i^{th} stage is given by following expression :

H_i = (surface area of the blank
- surface area of blank element at stage i
- surface area of corner radius element at stage i)/πD_i

where

D_i Current cup diameter.

H_i Current cup height.

7) Punch force

The empirical relations given by equations (2.1 to 2.3) are used to calculate maximum punch force. The maximum of these punch forces PF_{max} is taken as upper bound and is used for determining the press capacity.

8) Blank holding force

Blank holding force depends upon the amount of reduction, t / D_b ratio and yield strength of the material. The minimum blank holding force required is PF_{max} /3. The maximum value of blank holding force, BHF_{max} depends on the thickness of the sheet. Table 4.4 gives the BHF_{max} values for various blank thicknesses as percentage of punch force PF_{max}. In order to draw wrinkle free cup, maximum value of blank holding force should be used. From Table 4.4 we observed that for cup thickness greater than 1.270 mm. BHF_{max} will be less than $PF_{max}/3$. Therefore, $PF_{max}/3$ is used as the blank holding force in order to obtain wrinkle free cup.

4.2.2 Rules used in generative module.

Following rules are used in the generative module:

1) Trimming allowance is added to the height of cup to be drawn according to Table 4.1.

2) Blank diameter is calculated by equating surface area of the cup to the surface area of blank.

3) Percentage reduction is selected for drawing and redrawing

based on material properties and t/D_b ratio according to Table 4.2 and Table 4.3 .

4) Maximum reductions for drawing and redrawing at each stage are used.

5) If the maximum flow stress induced in cup wall is greater than maximum permissible flow stress, then annealing is required.

6) If annealing is done, then strain history is nullified.

7) While designing for mass production, number of stages should be minimized with minimum number of annealing stages.

8) For flat bottom cylindrical cups the punch profile radius should be $r_{pmin} < r_p < r_{pmax}$.

9) If punch profile radius $r_p > 0.3\ D_i$ then r_p is taken as $0.3\ D_i$.

10) The punch profile radius is reduced linearly from r_{pmax} for first draw to r_{pmin} for the last redraw.

11) If required punch profile radius is less than r_{pmin} then sizing pass should be introduced.

12) The optimum die profile radius used is 10t in order to use the maximum possible LDR to form cup without wrinkling.

13) The height of cup is determined by assuming that surface area remains constant.

14) Punch force is taken as maximum of the calculated values given by empirical equations.

15) If $t/D_b > 0.05$ and $1 / t > 3$ then blank holder is not needed.

16) If blank holder is not needed then single acting die can

be used.

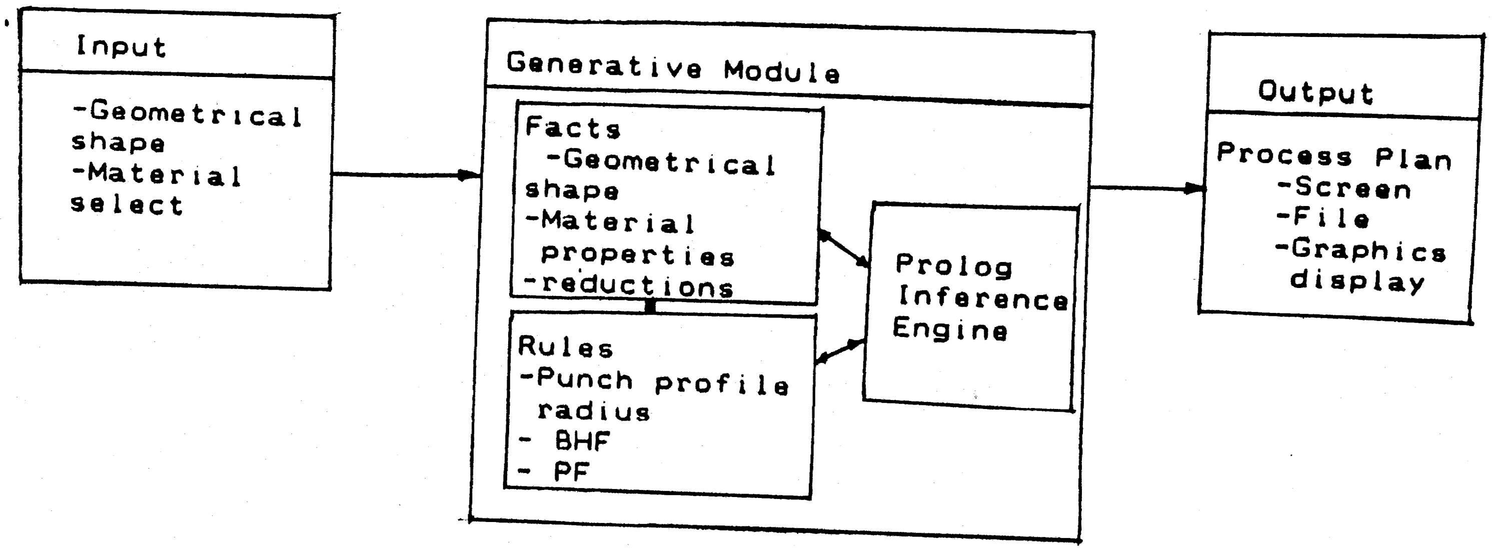
17) If a blank holder is required then a blank holding force which is equal to the max (F_{max} / 3, BHF_{max}) is used to obtain wrinkle free cup.

The process planning output can be stored in a file or presented on the screen in syntax form or displayed graphically.

4.3 Implementation

The present work attempts to develop a computerized process planing system for deep drawing operation. Every care has been taken to facilitate expansion of the software to include other features. The main program is written in Turbo Prolog. However, the graphics module is designed using Turbo Pascal. It is seen from section 4.2 that the process planning procedure is a set of rules without involved calculations. Prolog is chosen due to ease of its expansion as compared to other programming languages. The rules are represented in natural manner in terms of 'Horn Clauses'. Powerful unification and backtracking with depth first search save lot of programming effort. Furthermore, suitable data structures are available in Prolog. After compilation, the process planning package is in executable form and can be run 'stand alone' without Prolog and Pascal environments.

The process planning system is divided into three



4.3 Overview of the process planning system.

modules viz., Input, Generative and Output modules. An overview of the system is presented in Fig. 4.3. Each module is discussed separately in the following section.

4.3.1 Input module

Input from the user is taken in two steps. Firstly the geometrical shape component is specified. This is followed by material specifications of the component.

In the first module(INPUT.PRO), user specifies the geometrical shape of the component to be drawn. The shape of the component is described by height(Hc), diameter(Dc), corner radius (rc) and thickness (t) of cup to be drawn as shown in the Fig. 1.1. These attributes are given in mm. by the user.

In the second module(MATERIAL.PRO), material of the component is specified by user. In the current system data for six materials are available. The available materials are displayed in hierarchical manner. The root level displays the three main categories viz., Steel, Aluminum, and Brass. After selecting main categories sub-categories are displayed. Sub-categories are as follows:

1) Steel 1.1) Rimmed steel 1.2) Aluminium killed steel 1.3) Stainless steel.

2) Aluminium 2.1) Aluminium com. pure 2.2) Aluminium cr. alloy.

3) Brass 3.1) Yellow brass.

After selecting a sub-category, the corresponding material properties (Appendix A) are displayed. The user can change these properties, if necessary. As these properties are used in further analysis, final confirmation is taken from the user.

4.3.2 Generative module

The feasible process plan is generated using generative module (DEEP.PRO). The rules discussed in section 4.2 are converted into Prolog syntax. Prolog backtacking and unification is used to generate process plan efficiently.

Facts

Data are represented as facts in Prolog. Following three facts form the main data for rules.

1) Geometrical shape of cup.

2) Material specifications

3) Percentage reductions

The percentage reduction given in Tables 4.2 and 4.3 depends on the type of material selected. These specifications are stored in three data files - MS.DAT (For mild steel), AL.DAT (For aluminum), BR.DAT (for brass). Depending on the material chosen the corresponding files are consulted.

Rules

The rules are specified as Horn clauses. The rules described in section 4.3 forms the basis for the generation of process plan. The design steps described in the

section are carried out step by step applying the rules and a final process plan is generated.

4.3.3 Output module

The output(Process Plan) is presented to user in the following three ways, 1) Displayed on the screen in text. 2) Stored in the file 3) Graphically.

Text display

This form of the output enables the user to have a display of the process plan. The actual output consist of

a) The total number of stages.

b) Annealing stage (if recommended in the process plan).

c) The diameter, corner radius and height of the cup , press tonnage and blank holding force at each stage.

File

If the user intends to store a process plan generated in a session, option is provided to store the plan into a file. Sample outputs are given in Appendix-B

Graphical display

The graphics output of the shape of the component at all the intermediate stages is displayed on the terminal. This enables the user to have a visual appreciation of the reductions at each stage.

CHAPTER V

RESULTS AND DISCUSSION

The proposed software has been used to generate process plans for deep drawing of a cylindrical cup of 40 mm diameter and 200 mm height. In all thirteen different combinations of material and blank thickness are studied. The materials considered are yellow brass, rimmed steel, commercially pure Aluminium, and 18-8 stainless steel. The effect of t / D_b ratio and material properties on the generated process plan is studied. The details of the various materials and t / D_b ratios examined are given in Table 5.1. The Table also gives a summary of the process planning results, viz., blank diameter, number of drawing/redrawing stages, and number of annealing stages for the various cases. The detailed process planning output are generated. Process plans for various conditions of a typical component are given in Appendix-B. Figures 5.1 is a set of graphical outputs, for some of the cases. These figures depict the shape of the cup through its various stages of drawing/redrawing.

5.1 Discussion

The process planning results for the various cases are summarized in table 5.1. In case-1 it is observed that the component with t / D_b ratio of 0.1% is drawn in six drawing/redrawing stages with one annealing stage

Table 5.1 Results for various materials and t / D_b ratios.

Diameter of cup (D_c): 40 mm.

Height of cup (H_c): 200 mm.

Total reduction required ≃ 78.54 %

Case No.	Material used	t mm.	r_c* mm.	D blank mm.	t/D_b %	Maximum[a] possible reduction %	No. Stages	Number of annealing
1	Yellow Brass	0.19	1	184.84	0.10	67.5	6	1 (5[&])
2	Yellow Brass	0.56	2.25	185.14	0.32	67.5	4	1 (3)
3	Yellow Brass	1.4	6	186.01	0.75	67.5	4	1 (3)
4	Yellow Brass	2.0	8	186.46	1.0	67.5	3	1 (2)
5	Rimmed Steel	0.4	2	185.08	0.21	70	5	1 (4)
6	Rimmed Steel	0.9	4	185.55	0.485	70	4	1 (3)
7	Rimmed Steel	1.4	6	186.01	0.75	70	4	1 (3)
8	Rimmed Steel	2.0	8	186.46	1	70	3	1 (2)
9	Com. Pure Al.	0.36	1.5	184.96	0.19	76.46	5	1 (2,4)
10	Com. Pure Al.	0.63	2.6	185.22	0.34	76.46	5	1 (4)
11	Com. Pure Al.	1.4	6	186.02	0.75	76.46	3	1 (2)

cont...

12	Stainless Steel 18-8	1.4	8.5	186.58	0.75	32.85	4	3 (1,2,3)
13	Stainless Steel 18-8	2	8	186.46	1.00	32.85	4+1 sizing $	3 (1,2,3)

* r_c chosen nearly equal to 4t.

@ From material properties (Appendix A).

& Number in () gives the stage after which annealing is required.

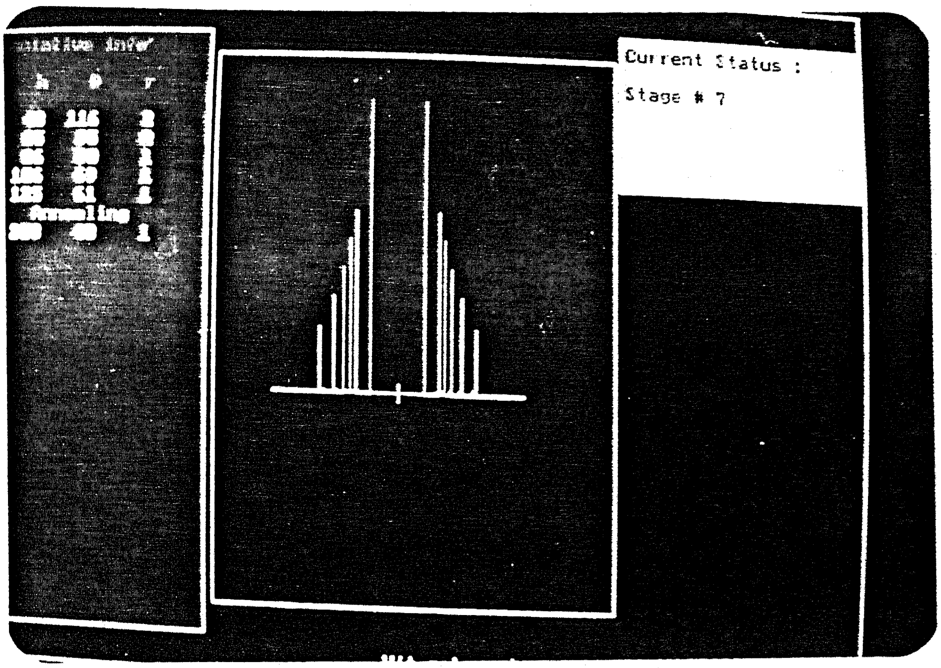
$ Same dimensions of diameter indicates the sizing operation.

after the fifth stage. For t / D_b ratio of 1.0% (case 4), the same cup needed only three stages with a annealing stage after the second draw. Therefore it is concluded that the number of drawing/redrawing stages decrease with increase in t / D_b ratio keeping H_c/D_c ratio constant. Similar conclusions can be drawn for cases listed against rimmed steel and commercially pure aluminium. Further, the number of annealing stages required could be predicted for each of the cases since the maximum possible reduction is less than the total reduction required 78.54%

In the case of 18-8 stainless steel (cases 12 and 13, Table 5.1), it is observed that the number of draws/redraws is not affected by t / D_b ratio. This is due to the fact that the maximum possible reduction without annealing in first stage is very low (32.85%) as compared to the total required reduction of 78.54%. Furthermore, the component requires a annealing stage after every drawing/redrawing indicating that it would not be economical to draw this component from stainless steel. It is also observed that, in case of S.No. 13, an additional sizing pass is indicated because the required cup profile radius is less than the minimum admissible profile radius of 6t for 18-8 stainless steel.

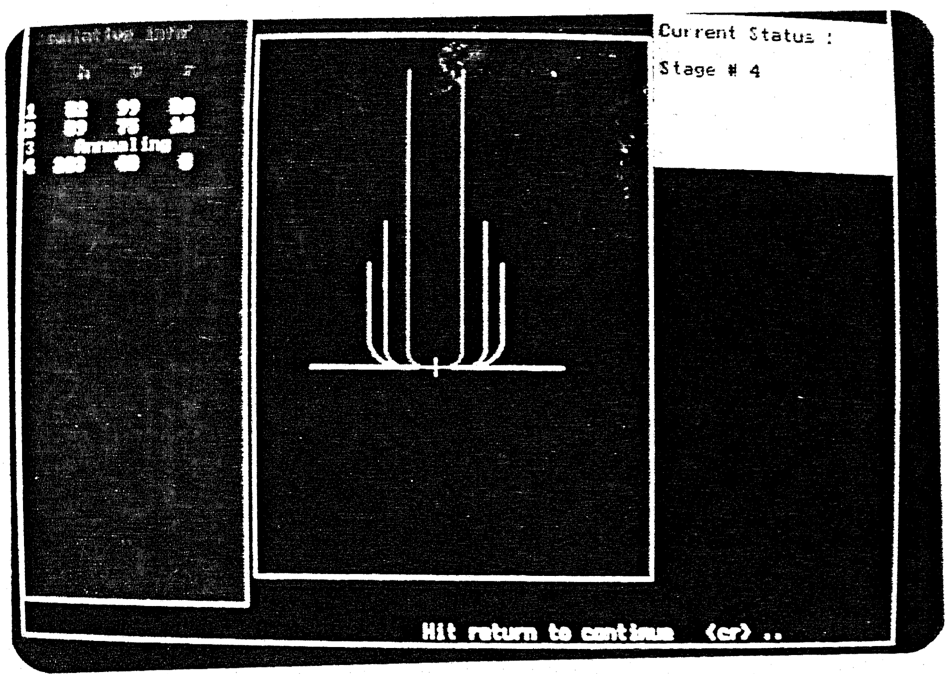
It may be noted that the process planning methodology incorporates a strategy to check if annealing at previous stage would be beneficial. Throughout this

results presented for case-6 (Appendix-B) reveal the following. Ordinarily, the component would have required five drawing/redrawing stages with annealing after the fourth stage. It is observed that reduction required at the fifth stage is 30.02%. A check at the previous redrawing stage indicates that an improvement is possible if annealing is carried out at that stage. The application of this back tracking strategy with regard to annealing stage shows that the component now can successfully be drawn in four stages with annealing after the third stage. This backtracking strategy exploits the fact that the possible reduction in the subsequent stages is generally much lower than the admissible reduction at the first draw after annealing.



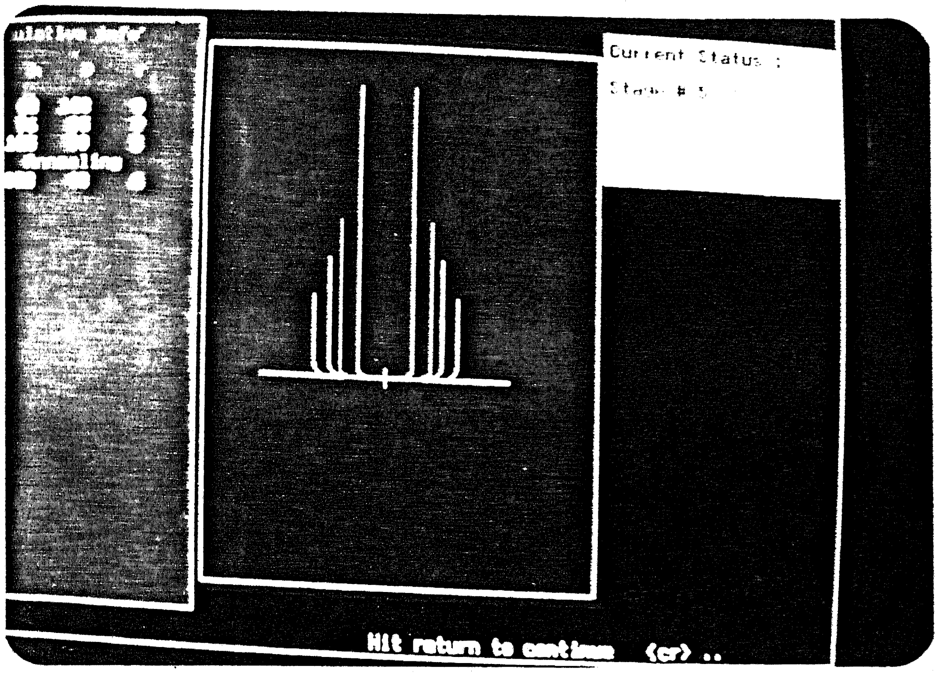
Material : Yellow Brass thickness : 0.19 mm

a) Case no 1



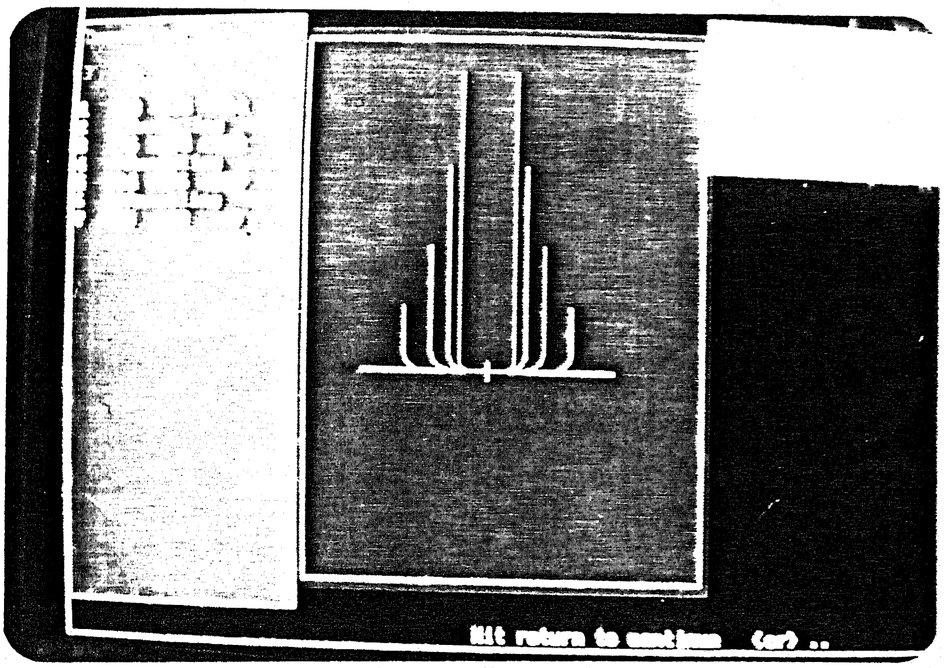
Material : Yellow Brass thickness : 2.0 mm

b) Case no. 4



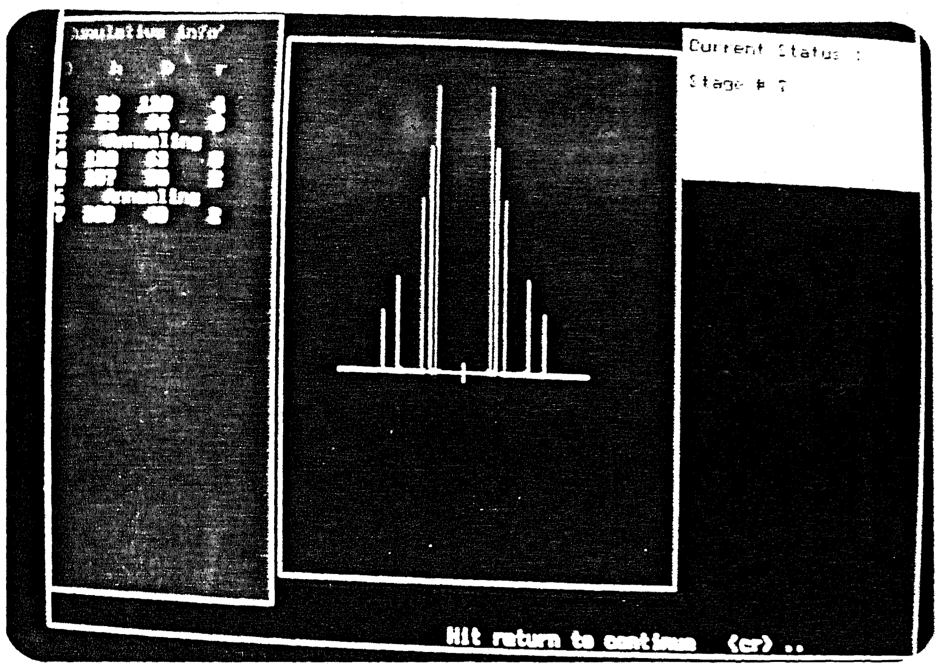
Material : Rimmed steel thickness : 0.9 mm

c) Case no. 6



Material : stainless steel Thickness : 1.4 mm

d) Case no. 12



Material : Com. pure. Aluminium thickness 0.36 mm

e) case no. 9

Fig. 5.1 Graphical outputs of a typical component.

CHAPTER VI

CONCLUSIONS

6.1 CONCLUSION

A computerised process planning methodology for deep drawn cylindrical shape components is developed and implemented. The task of developing the process plan is extremely complex and requires decision making on the part of the process planner at several stages utilizing empirical relationships, standard data sources, experimental data as well as intuitive judgment based on experience. The present work draws upon all the sources to develop process plan for a given drawn cylindrical shaped component. The inputs to the system are various attributes of the finished component to be drawn, viz., diameter, height, cup profile radius, thickness, and material of the cup. The first step in the development of the process plan is to determine the blank size. The component is divided into primitive elements such as flange, taper, annular, flat ring and base. A general purpose program with capabilities to determine blank diameter for all types of axisymmetric shapes has been developed. The input to the program is provided as a sequence of primitive elements. The overall process planning exercise is limited to deep drawn cylindrical shaped components, even though the blank diameter

determination software is general purpose. The program provides a graphical display to facilitate visual observations and modification. The generative module of process planning software determines the cup diameter, height, corner radius, punch force, and blank holding force. Further, it determines the number of drawing/redrawing stages as well as annealing requirements, for each stage of drawing/redrawing,. The output is displayed on the screen in text format or is stored in a file or displayed graphically to have visual appreciation of reductions at each stage.

6.2 Scope for further work

During the development and implementation of proposed process planning system for deep drawing operation, the following possibilities have been envisaged for further extension of the work.

1) The material database in the present work is restricted to only three broad categories of materials, viz., Aluminium, Brass and steel. The database can be expanded to include properties of other materials.

2) The present system does not consider the capacities of the various processes available on the shop floor. A natural extension , therefore, would be to integrate planning activity with machine selection. If the press of the required capacity is not available, a process plan which is constrained by the available press capacities needs to be developed.

3) Computer aided design of dies based on the process plan generated would provide a step towards computer integrated manufacturing of deep drawn components.

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APPENDIX-A

Material properties

Material	Minimum Yield Point Kgf/sq. mm.	Maximum Yield Point Kgf/sq. mm.	Modulus of strain hardening. Kgf/sq. mm.	Tensile strength Kgf/sq. mm.
Yellow Brass	28.18	66.2274	84.5456	35.2273
Rimmed Steel	24.659	49.3182	59.8864	31.7046
Stainless steel	35.2273	116.2502	281.8187	66.93152
Aluminium Killed steel	24.659	49.3182	59.8844	31.7046
Aluminium Com.pure (2S)	5.6363	14.795	17.61336	9.1591
Aluminium Cr-alloy (52S)	44.79	26.06	26.77	20.431189

APPENDIX-B

Material Used : BRASS_YELLOW
Sheet Thickness : 0.19 mm.
Blank diameter : 184.8413 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	116.4500	1.9	43.16651
2	95.48905	1.672	64.63989
3	80.21080	1.444	85.62958
4	68.98128	1.216	105.9041
5	60.70353	0.988	124.9902
*	ANNEALING		
6	40	1	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	4.523882	3.031001
2	3.709583	2.485420
3	3.116050	2.087753
4	2.679803	1.795468
5	2.358226	1.580011
*	ANNEALING	
6	1.553930	1.041133

Percentage Reductions Selected [0.63,0.82,0.84,0.86,0.88]
Minimum yield point 28.1818 Kgf/sq.mm
Maximum yield point 66.2274 Kgf/sq.mm
Modulus of Strain hardening 84.5456 Kgf/sq.mm
Tensile strength 35.2273 Kgf/sq.mm

==

Result No. 1

Material Used : BRASS_YELLOW
Sheet Thickness : 0.56 mm.
Blank diameter : 185.1436 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	107.3833	5.6	49.81260
2	84.83282	4.48	77.29792
3	68.71458	3.36	105.6548
*	ANNEALING		
4	40	2.25	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	12.29540	5.409978
2	9.713369	4.273882
3	7.867829	3.461844
*	ANNEALING	
4	4.580005	2.015202

Percentage Reductions Selected [0.58,0.79,0.81,0.83,0.86]
Minimum yield point 28.1818 Kgf/sq.mm
Maximum yield point 66.2274 Kgf/sq.mm
Modulus of Strain hardening 84.5456 Kgf/sq.mm
Tensile strength 35.2273 Kgf/sq.mm

==

Result No. 2.

```
Material Used       :      BRASS_YELLOW
Sheet Thickness :      1.4  mm.
Blank diameter     :      186.0190 mm.
```

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	102.3104	14	51.26746
2	79.80217	11.2	82.29573
3	63.84173	8.4	114.9221
*	ANNEALING		
4	40	6	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	29.28640	9.762136
2	22.84339	7.614466
3	18.27471	6.091573
*	ANNEALING	
4	11.45001	3.816671

```
Percentage Reductions Selected  [0.55,0.78,0.8,0.82,0.85]
Minimum yield point             28.1818  Kgf/sq.mm
Maximum yield point             66.2274  Kgf/sq.mm
Modulus of Strain hardening     84.5456  Kgf/sq.mm
Tensile strength                35.2273  Kgf/sq.mm
==================================================================
```

Result No. 3.

```
Material Used       :      BRASS_YELLOW
Sheet Thickness :      2  mm.
Blank diameter     :      186.4667 mm.
```

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	98.82739	20	52.41764
2	75.10882	14	89.34761
*	ANNEALING		
3	40	8	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	40.41339	13.47113
2	30.71417	10.23805
*	ANNEALING	
3	16.35716	5.452387

```
Percentage Reductions Selected  [0.53,0.76,0.79,0.81,0.84]
Minimum yield point             28.1818  Kgf/sq.mm
Maximum yield point             66.2274  Kgf/sq.mm
Modulus of Strain hardening     84.5456  Kgf/sq.mm
Tensile strength                35.2273  Kgf/sq.mm
==================================================================
```

Result No. 4

Material Used : RIMMED_STEEL
Sheet Thickness : 0.9 mm.
Blank diameter : 185.5580 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	107.6236	9	48.05566
2	85.02269	7.2	75.97684
3	68.86837	5.4	104.7678
*	ANNEALING		
4	40	4	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	17.32905	5.776352
2	13.68995	4.563318
3	11.08886	3.696288
*	ANNEALING	
4	6.440612	2.146870

Percentage Reductions Selected [0.58,0.79,0.81,0.83,0.86]
Minimum yield point 24.659 Kgf/sq.mm
Maximum yield point 49.3182 Kgf/sq.mm
Modulus of Strain hardening 59.8864 Kgf/sq.mm
Tensile strength 31.7046 Kgf/sq.mm
===

Result No. 6

Material Used : RIMMED_STEEL
Sheet Thickness : 0.4 mm.
Blank diameter : 185.0836 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	111.0501	4	47.10274
2	88.84013	3.4	72.27776
3	72.84891	2.8	97.77805
4	61.92157	2.2	121.5964
*	ANNEALING		
5	40	2	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	7.947013	3.973506
2	6.357610	3.178805
3	5.213240	2.606620
4	4.431254	2.215627
*	ANNEALING	
5	2.862494	1.431247

Percentage Reductions Selected [0.6,0.8,0.82,0.85,0.87]
Minimum yield point 24.659 Kgf/sq.mm
Maximum yield point 49.3182 Kgf/sq.mm
Modulus of Strain hardening 59.8864 Kgf/sq.mm
Tensile strength 31.7046 Kgf/sq.mm
===

Result No. 5

Material Used : RIMMED_STEEL
Sheet Thickness : 1.4 mm.
Blank diameter : 186.0190 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	102.3104	14	51.26746
2	79.80217	11.2	82.29573
3	63.84173	8.4	114.9221
*	ANNEALING		
4	40	6	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	25.62552	8.541843
2	19.98791	6.662637
3	15.99033	5.330110
*	ANNEALING	
4	10.01873	3.339577

Percentage Reductions Selected [0.55,0.78,0.8,0.82,0.85]
Minimum yield point 24.659
Maximum yield point 49.3182
Modulus of Strain hardening 59.8864
Tensile strength 31.7046
==

Resolt. No. 7

Material Used : RIMMED_STEEL
Sheet Thickness : 2 mm.
Blank diameter : 186.9013 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	99.05770	20	52.56373
2	75.28385	14	89.57273
*	ANNEALING		
3	40	10	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	35.44401	11.81467
2	26.93745	8.979151
*	ANNEALING	
3	14.31247	4.770824

Percentage Reductions Selected [0.53,0.76,0.79,0.81,0.84]
Minimum yield point 24.659 Kgf/sq.mm
Maximum yield point 49.3182 Kgf/sq.mm
Modulus of Strain hardening 59.8864 Kgf/sq.mm
Tensile strength 31.7046 Kgf/sq.mm
==

Resolt. No. 8

Material Used : ALUMINUM_COM_PURE
Sheet Thickness : 0.36 mm.
Blank diameter : 184.9629 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	120.2258	3.6	39.05263
2	96.18071	3.06	63.15785
*	ANNEALING		
3	62.51746	2.52	119.7710
4	50.01397	1.98	157.4079
*	ANNEALING		
5	40	1.5	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	1.769880	1.008831
2	1.415904	0.807065
*	ANNEALING	
3	0.920337	0.524592
4	0.736270	0.419673
*	ANNEALING	
5	0.588851	0.335645

Percentage Reductions Selected [0.65,0.8,0.94]
Minimum yield point 5.6363 Kgf/sq.mm
Maximum yield point 14.795 Kgf/sq.mm
Modulus of Strain hardening 17.61336 Kgf/sq.mm
Tensile strength 9.1591 Kgf/sq.mm

Result No. 9

Material Used : ALUMINUM_COM_PURE
Sheet Thickness : 0.63 mm.
Blank diameter : 185.2273 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	111.1364	6.3	45.85841
2	84.46367	5.355	77.43865
3	66.72630	4.41	109.4033
4	57.38462	3.465	133.1950
*	ANNEALING		
5	40	2.6	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	2.863124	1.259774
2	2.175974	0.957428
3	1.719020	0.756368
4	1.478357	0.650477
*	ANNEALING	
5	1.030490	0.453415

Percentage Reductions Selected [0.6,0.76,0.79,0.86]
Minimum yield point 5.6363 Kgf/sq.mm
Maximum yield point 14.795 Kgf/sq.mm
Modulus of Strain hardening 17.61336 Kgf/sq.mm
Tensile strength 9.1591 Kgf/sq.mm

Result No. 10

Material Used : ALUMINUM_COM_PURE
Sheet Thickness : 1.4 mm.
Blank diameter : 186.0190 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	96.72990	14	57.55700
2	67.71093	9.8	105.4560
*	ANNEALING		
3	40	6	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	5.537734	1.845911
2	3.876414	1.292138
*	ANNEALING	
3	2.289978	0.763326

Percentage Reductions Selected [0.52,0.7,0.76,0.79]
Minimum yield point 5.6363 Kgf/sq.mm
Maximum yield point 14.795 Kgf/sq.mm
Modulus of Strain hardening 17.61336 Kgf/sq.mm
Tensile strength 9.1591 Kgf/sq.mm

==

Resolt No. 11

Material Used : STAINLESS_STEEL_18_8
Sheet Thickness : 1.4 mm.
Blank diameter : 186.5766 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	125.2728	14	30.39114
*	ANNEALING		
2	84.11176	12.13333	75.77356
*	ANNEALING		
3	56.47502	10.26666	134.4035
*	ANNEALING		
4	40	8.5	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	44.82431	14.94143
*	ANNEALING	
2	30.09631	10.03210
*	ANNEALING	
3	20.20752	6.735840
*	ANNEALING	
4	14.31253	4.770845

Percentage Reductions Selected [0.55,0.78,0.8,0.82,0.85]
Minimum yield point 35.2273 Kgf/sq.mm
Maximum yield point 116.25023 Kgf/sq.mm
Modulus of Strain hardening 281.8187 Kgf/sq.mm
Tensile strength 66.931952 Kgf/sq.mm

==

Resolt No. 12

Material Used : STAINLESS_STEEL_18_8
Sheet Thickness : 2 mm.
Blank diameter : 186.4667 mm.

Stage no.	Diameter mm.	Radius mm.	Height mm.
1	125.1990	20	27.17474
*	ANNEALING		
2	84.06223	17.33333	73.01511
*	ANNEALING		
3	56.44176	14.66666	132.0849
*	ANNEALING		
4	40	12	200.9996
5	40	8	202.9996

Stage no.	Press Tonnage	Blank Hold Down Force(Tons)
1	63.99702	21.33234
*	ANNEALING	
2	42.96942	14.32314
*	ANNEALING	
3	28.85088	9.616963
*	ANNEALING	
4	20.44648	0
5	5.046550	0

Percentage Reductions Selected [0.53,0.76,0.79,0.81,0.84]
Minimum yield point 35.2273 Kgf/sq.mm
Maximum yield point 116.25023 Kgf/sq.mm
Modulus of Strain hardening 281.8187 Kgf/sq.mm
Tensile strength 66.931952 Kgf/sq.mm
==

Resolt No. 13

APPENDIX C

USER'S MANUAL

This user manual provides the user a comprehensive guide to the blank size calculation program and process planning system.
A program 'Blankare' written for the purpose of determining blank area which is invoked by

A> Blankare

Input to this program is given interactively in a specific sequence as described in Chapter III .
The program 'DEEP.EXE' along with the data files MS.DAT, AL.DAT, BR.DAT forms the process planning software. This program can be invoked by

A> DEEP

As program is invoked, information about geometrical shape of the component should be provided by user. Selection of material properties is menu driven. Using cursor keys locate an option and press <ENTER> or <RETURN> key to select an option.

Generated process plan is stored in the file name given by user. This file can be printed (See Appendix-B). To compare relative shapes an option is provided. To see graphics display ensure that required graphics card (ECG) is available on the PC-XT/AT, on which the program is to be run. Program DRAW.EXE provides graphical display of various stages, which is invoked by DEEP.EXE program.